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Particulate Technology R and D Program

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Dust	ling	Particulate	11G 12A
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An Overview Of The EPA Particulate Technology R&D Program

Norman Plaks

Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina

A number of key projects in the Environmental Protection Agency (EPA) particulate R&D program having applicability to industry are presented. For electrostatic precipitators (ESP) there is presented the result of work on large diameter discharge electrodes which provide a decrease in penetration of up to a factor of 4 when compared to conventional small diameter electrodes. Also discussed is the multistage ESP which provides a collection efficiency that would require a collecting plate area 4 or 5 times larger with conventional ESP technology. The E-SOX technology makes use of the multistage concept to free up space in the ESP for SO₂ removals of up to 90%. Electrostatically augmented fabric filtration provides a reduction in pressure drop of about 50% as compared to conventional fabric filtration. Wind tunnel modeling of windbreaks for material storage piles indicates a potential for providing engineering design data that would allow significant emission reduction caused by wind erosion.

The Environmental Protection Agency particulate R&D program is concerned with the development of control technology for both ducted and fugitive sources of particulate matter. Additionally, work is underway on development of operation and maintenance procedures and the development of technology for reducing the emission of condensable aerosols. The work is distributed between the in-house facility at Research Triangle Park, North Carolina, and various research organizations. In recent years an increasingly larger amount of the work is being done in-house; today the thrust of much of the extramural research is support of the in-house activities.

Table I. Comparison of large and small diameter discharge electrodes.*

Resistivity ohm-cm	8×10^{10}	2×10^{12}
Electric field ratio (E_L/E_S)	1.60	1.19
Current density ratio (j_L/j_S)	0.41	0.69
Power ratio (P_L/P_S)	0.55	0.81
Overall migration velocity ratio (w_L/w_S)	1.12	1.33
Penetration ratio (P_{TL}/P_{TS})	0.80	0.25

* Subscript L refers to large diameter electrode and subscript S refers to small diameter electrode.

Historically, the program, in its ducted source work, was most heavily focused upon the control of emissions from the combustion of coal in utility and industrial boilers. However, because control technologies such as electrostatic precipitation and fabric filtration are generic by nature, they do have application to other industries.

In this overview paper a number of the key generic technology projects in the particulate R&D program that are concerned with electrostatic precipitation, fabric filtration, and fugitive emission control are presented. They were picked for inclusion in this paper on the basis of their expected applicability to industry.

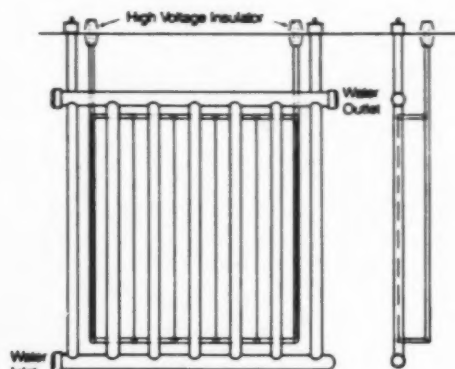


Figure 1. Cold-pipe precharger.

Electrostatic Precipitators

EPA's electrostatic precipitator (ESP) research has concentrated on improving performance and operation, especially with high resistivity dusts and back corona, decreasing size and cost, upgrading performance for operation with desulfurization systems, integrating sulfur dioxide control into the ESP, and developing performance and cost models.

Historically, with low resistivity dusts, ESPs have been designed for high corona currents. Even with these high corona currents the absence of a back corona problem allows devel-

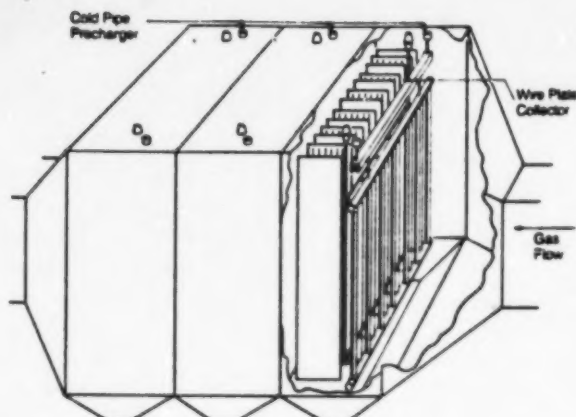


Figure 2. Multistage electrostatic precipitator.

opment of high field strength. As a consequence, the ESPs operated well and the particles were easily charged and collected. High corona currents were achieved by use of small diameter discharge wires (approximately 0.3 cm) or use of electrodes with a multiplicity of discrete discharge points. Where the allowable useful current is limited by high resistivity, the low corona onset voltage and fairly steep voltage/current relationship results in a decreased electric field strength. The combination of low current density and electric field produced by conventional discharge electrodes requires that a high SCA be provided to meet emission standards.

Experimental studies at the EPA 840 actual m^3/min field pilot unit at TVA's Bull Run power plant and the in-house 28 actual m^3/min pilot ESP have shown that the use of larger diameter, smooth-surface electrodes (approximately 1 cm in diameter) can provide a significant improvement in ESP performance—especially when high resistivity dust is collected. The large diameter electrodes allow operation at high field strengths and useful current densities. The operating current density, and thus the useful operating power, for the

large diameter electrodes was found to be less than that for conventional size electrodes. For moderate ($8 \times 10^{10} \text{ ohm-cm}$) to high ($> 2 \times 10^{12} \text{ ohm-cm}$) resistivity dusts, the increase in the electric field more than compensates for the reduction in useful power. As can be seen from Table I, the large diameter wires reduce the penetration for high resistivity dust by a factor of 4 and the penetration for moderate resistivity dust by a factor of 1.25. Economic analysis has shown that the large diameter wire technology is applicable in both new and retrofit situations when the dust resistivity is greater than about $8 \times 10^{10} \text{ ohm-cm}$. The application of this technology is being further pursued.

In conventional ESPs particle charging and collection take place in the same electrical section. It has been found that, for the higher resistivity dusts, separation and optimization of the charging and collection steps can lead to significant improvements in performance.

A number of precharger techniques have been worked upon including the trielectrode,¹ cold-pipe,² and charged droplet. One of the most promising is the cold-pipe precharger shown in Figure 1. It consists of discharge wires interspersed with grounded pipes through which cooling water flows. The purpose of the cooling water is not to cool the gas stream but to cool the dust layer that forms on the pipes. Cooling the dust layer decreases the resistivity, thereby allowing high field strength and current which puts high charge levels on the particles. The direction of gas flow for the front view of the cold-pipe, which is on the left side of the figure, is perpendicular into the paper; for the side view the gas flow is from left to right.

Combining the cold-pipe precharger with wire-plate collectors using large diameter wires provides an even further improvement in performance. Large diameter wires in the collector sections allow development of high field strengths and also provide sufficient corona current to clamp the dust layer to the plates, thereby minimizing nonrapping reentrainment. Figure 2 shows the multistage ESP which consists of collector sections each of which is preceded by a cold-pipe precharger. With high resistivity particulate matter a multistage ESP will give the same collection efficiency as a conventional ESP operating with relatively low currents and

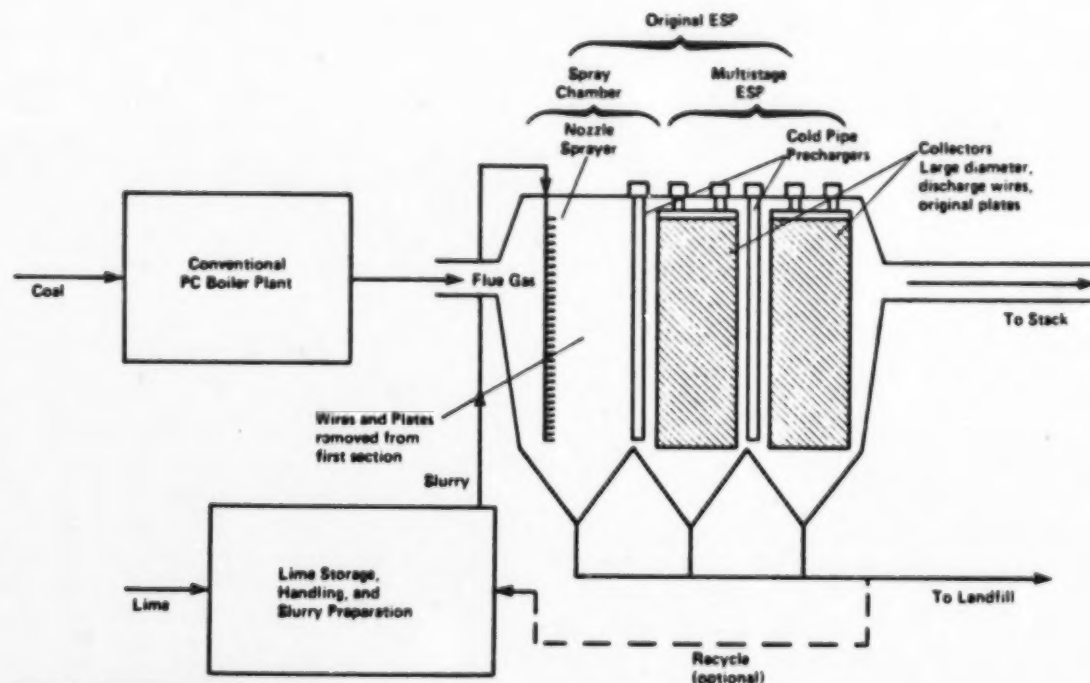


Figure 3. Schematic of E-SOX process.

fields and having 4 or 5 times the collecting plate area. Operation of the multistage ESP with the cold-pipe precharger and large diameter wires in the collector sections has been done on the EPA in-house 28 actual m³/min ESP. Further work on this concept is scheduled on the EPA 425 actual m³/min ESP at Colorado Public Service's Valmont power station.

Multistaging, when retrofitted to an ESP that is working well and is in compliance with the particulate matter regulations, will have more capacity than is actually needed. This suggests that some portion of the ESP internals can be removed. This freed up space, fitted with suitable nozzles, can be used for removal of sulfur dioxide from a flue gas by injecting droplets of an alkaline reagent.

This system, which has been named E-SOX, for the removal of sulfur dioxide along with the particulate matter in an ESP, is shown schematically in Figure 3. The ESP has had some internals at the inlet removed; cold-pipe prechargers and large diameter wires are installed in the remainder of the ESP. The alkali reagent shown being used here is a high calcium lime that has been slaked and slurried by techniques that have been developed for conventional spray drying flue gas desulfurization.

The E-SOX system has been evaluated on the in-house 28 actual m³/min ESP using two-fluid nozzles for the alkali reagent injections. The sulfur dioxide removal results are shown in Figure 4. Two reagents were used, sodium carbonate solution and lime slurry. With the sodium carbonate inlet concentrations of 15 and 30% by weight and at flow rates ranging from 26 to 75 L/hour, the sulfur dioxide removal ranged, for

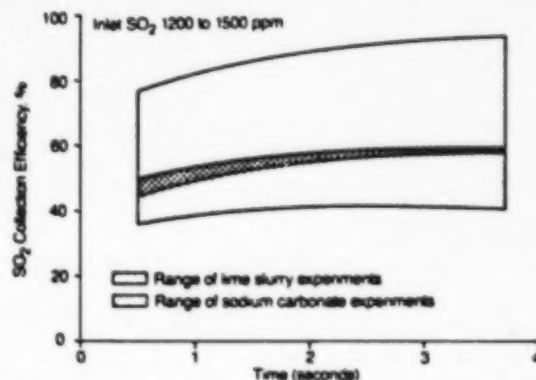


Figure 4. E-SOX data for sodium carbonate and lime slurry experiments.

an inlet concentration of 1200 to 1500 ppm, from about 50% to almost 90%, within 2 seconds of residence time. With a slurried lime injection, whose concentration was 7 and 15% by weight, the sulfur dioxide removal in the same 2 seconds of residence time ranged from about 40% to almost 60%. Maximum sulfur dioxide was removed at the higher injection rates. The removal was not found to be highly sensitive to reagent concentration. For the lime experiments the maximum stoichiometry of calcium to sulfur was about 1.8 based upon inlet sulfur dioxide. In both cases the injected droplets were completely dried in considerably less than 2 seconds, and the deposits on the ESP could be rapped off. In this series of experiments no attempt was made to optimize the sulfur dioxide removal. In a typical ESP retrofit, enough of the internals should be removable to obtain 2 seconds of residence time. The remainder of the ESP can be multistaged not only to regain original particulate collection performance but also to capture the injected reagent.

The costs for E-SOX have not been fully worked out. However, it is expected that the process should be among the lowest cost of the various flue gas desulfurization techniques. The use of an existing ESP makes it unnecessary to add equipment, such as a spray drying chamber, for sulfur dioxide capture; the lime system is the same as is required for some of the other processes. One advantage of E-SOX is that the injection of a large quantity of droplets lowers the gas temperature and volume which causes a reduction in particle resistivity and an increase in SCA. The E-SOX project is expected to be moved onto a larger pilot unit using actual flue gas as the next stage in its development.

E-SOX, if successfully developed, would be a low-cost retrofit for reducing emissions of sulfur dioxide from coal-fired power plants. This is significant for several reasons: 1) coal-fired power plants with ESP particulate control technology represent the largest source category for sulfur dioxide emissions in the U.S., and 2) the high cost of controlling sulfur dioxide with existing technology is a major issue to be considered in air pollution policy analysis. It would be especially useful for those situations in which there is not room for a spray drying chamber.

Fabric Filtration

Historically, fabric filtration has been used for a considerable time in industry. More recently with increasing use of low sulfur coals, with their high resistivity fly ashes, it is being applied more frequently to utility and industrial boiler particulate matter control.

In the EPA particulate program it has been concluded that, of all the parameters involved in fabric filtration design, electrostatics, when properly applied, is the dominant.

Electrostatically augmented fabric filtration (ESFF) is a technique in which an electrostatic field is established across

the fabric to cause preferential deposition of the particulate matter on some areas while leaving other areas open to gas flow. This open area causes a lowered pressure drop for the baghouse. Much of the work to date has been with the electric field parallel to the surface of the fabric. Typically the field was generated between electrodes, at the surface of the fabric, running the length of the bag, and placed about 2 cm apart. The electric field strength is from about 2 to 8 kV/cm. In pulse-jet operation the wire support cage is adapted for developing the electric field as shown in Figure 5.³ Adjacent wires are insulated from each other thereby allowing the cage itself to be electrified. For reverse-air, which does not use a cage, stainless steel yarns have been woven into the fabric warp as shown in Figure 6. The fabric is fiberglass with a Teflon finish; the yarn is 316 stainless steel having 90 fibers each 22 μ m in diameter.⁴ The alternate yarns have the electric field developed between them, the same as in pulse-jet.

The ESFF effect has been shown for fly ashes on the small in-house baghouses. It has been shown for both reverse-air and

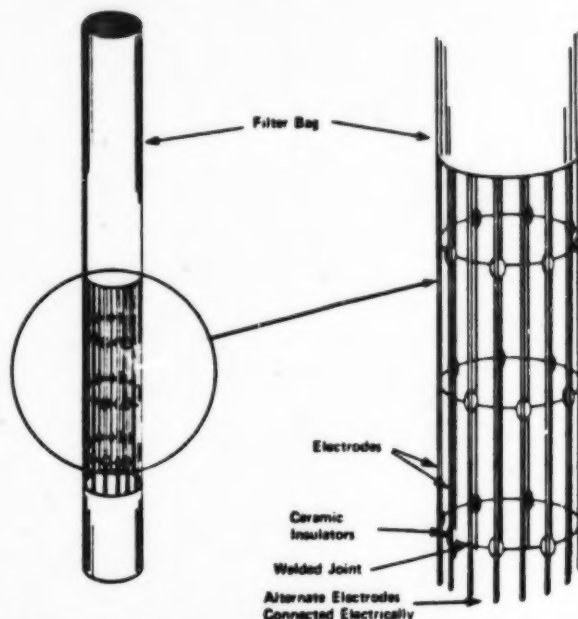


Figure 5. Pulse-jet ESFF electrode/bag assembly.

pulse-jet with the EPA 28 actual m^3/min pilot unit having 2.4 m bags on an industrial boiler at the DuPont Waynesboro facilities. It has been operating for about 14 months, using reverse-air, at the EPA 140 actual m^3/min pilot unit at the Southwest Public Service Harrington power station in Amarillo. At the Harrington power plant the bags were full utility size, each being 9.14 m long and 0.3 m in diameter as shown in Figure 6.

Typically, for fly ash the pressure drop across an ESFF baghouse is about 50% of the pressure drop across a conventional baghouse.^{3,5} This means that one can minimize the pressure drop and consequently the fan power or else decrease the number of bags and consequently the capital cost.

A series of experiments were performed in-house on both reverse-air and pulse-jet using redispersed particulate matter from a spray drying process used in sulfur dioxide capture. In spray drying a lime slurry is injected into a chamber to react with the sulfur dioxide. The resulting mixture consists of fly ash, and reacted and unreacted lime. For spray drying by-product particulate matter, the pressure drop was reduced by about a factor of 6 as compared to conventional filtration.

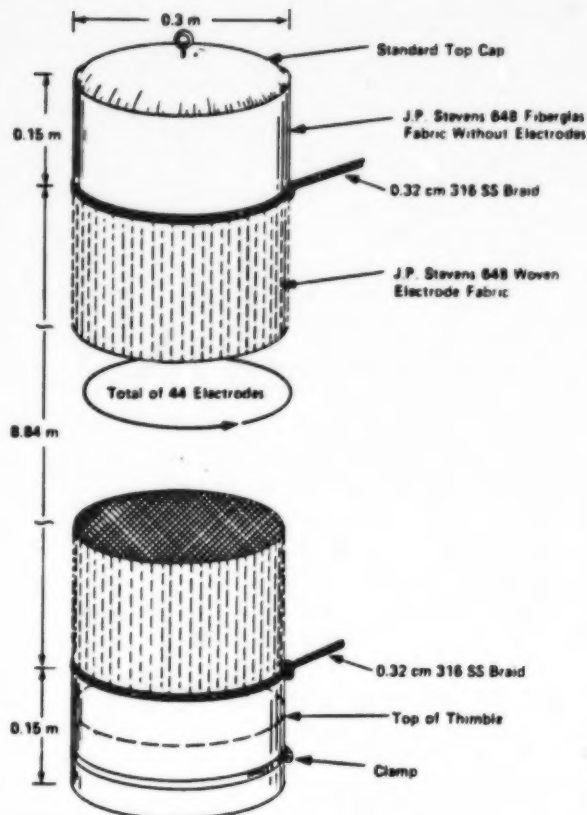


Figure 6. Reverse-air woven-in electrode ESFF bags.

Figure 7 is a pressure vs. time trace which shows dramatically the effects of turning the field on. At the start, with the power off, the pressure drop was continuing to rise and would have eventually gone off the chart if continued. The pressure drop started to respond immediately to turning on the field.

The ESFF effect that has been discussed up to now has been based upon the action of an electric field upon particulate matter containing only natural charge. No corona for charging the particles was generated. The measured natural charge on fly ash was about 0.1 to 0.2 $\mu\text{C}/\text{g}$, for spray drying byproduct the charge-to-mass was 1 to 2 $\mu\text{C}/\text{g}$. The difference in the pressure drop reduction for fly ash as compared to spray drying material shows the effect of this difference. Varying the electric field has also been seen to affect the pressure drop reduction.

Work is underway on techniques in ESFF for simultaneously increasing the field strength and increasing the charge on the particles. There is good indication that by doing this

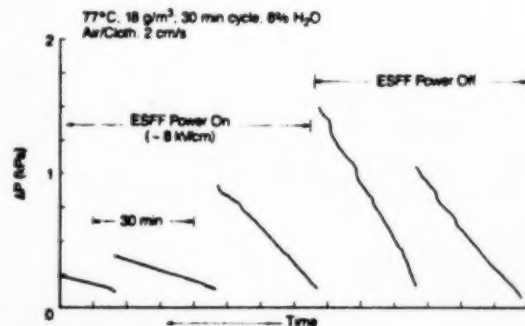


Figure 7. Effect of turning ESFF field on.

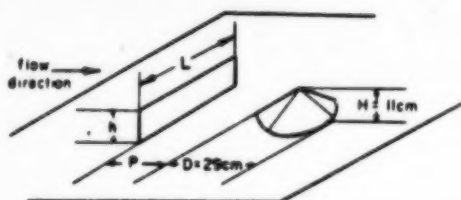
CONTROL TECHNOLOGY NEWS

it would be possible to achieve pressure drop reduction for most particulate matter that will equal that which was achieved with spray drying material.

Fugitive Emissions

Several projects are underway on investigating control technology for fugitive emissions. One project that may have significance for industries is the development of engineering design data for control of wind blown particulate matter from storage piles by use of windbreaks.

Windbreaks for the control of windblown particulates are not new. However, very little engineering data are available on how to engineer them. To develop these data, wind tunnel experiments have been conducted to determine the optimal windbreak porosity, size, and location for storage pile fugitive



Windbreak Specifications	
Porosity	50%, 65%
h	0.5H, 1.0H, 1.5H
L	1.0D, 1.5D
P	1H, 3H

Figure 8. Conical storage pile and windbreak placement and specifications.

dust control.⁶ The low speed, open return EPA Meteorological Wind Tunnel has a test section 2.1 m high by 3.7 m wide by 18.3 m long. In the wind tunnel a neutrally stratified, rural atmospheric boundary layer was simulated.

In the first set of experiments a nonerodible material was used to represent a conical storage pile as shown in Figure 8. Straight sections of windbreak material of various combinations of porosity, height, length, and location were placed upwind of the pile. The windbreak height and length are given in terms of pile height and base diameter, respectively, and the position is the distance between the windbreak and pile base given in terms of pile height. There were 24 combinations of the parameters.

The surface wind velocity profiles were mapped using calibrated thermistors for the model pile without windbreaks in place. In Figure 9 a top view is shown with contours of normalized wind speed, U/U_{10} , where U is the wind speed measured at the pile surface and U_{10} is the wind speed at the equivalent full-scale height of 10 m in the absence of the pile. The wind velocity is highest on the upstream face near the crest extending down both sides.

Typical velocity reduction percentages are shown in Figure 10. Velocity reductions of about 75% are indicated for the previously identified high velocity areas of the cone. Significant velocity reductions are also indicated for other portions of the cone. Similar work is being completed for oval storage piles.

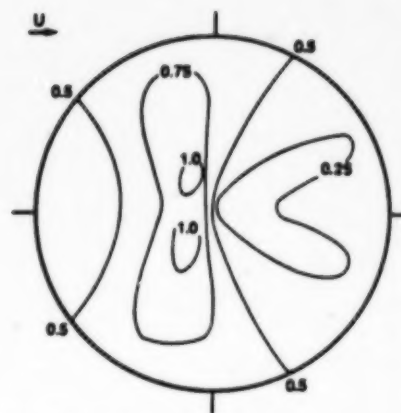


Figure 9. Surface wind velocity profile for conical storage pile model without windbreak.

It is assumed that a reduction in surface wind velocity will result in a decrease in fugitive wind blown emissions from the storage pile. Future work is being planned to verify these results on full-scale storage piles. If the verification is successful, a useful engineering design tool would be available to various industries.

Other Activities

In addition to the work described in previous sections, EPA has a strong program in modeling and fundamentals. The purpose of the modeling/fundamentals program is to provide design and performance models for the particulate control devices, which are based on a sound understanding of the underlying physics of the particulate collection process. The ESP work has resulted in a computer model that is in widespread use by vendors, users, and researchers,⁷ especially for utility applications. Work is underway to improve the ESP model in the areas of effects of electrode geometry, electrical conditions, and space charge. This new ESP model computes the voltage and current for several common electrode geometries. The results are presented both numerically and as a video display of the electric field and the current distribution. The ability to display the electrode geometry, electric fields, and current distribution allows the designer to make

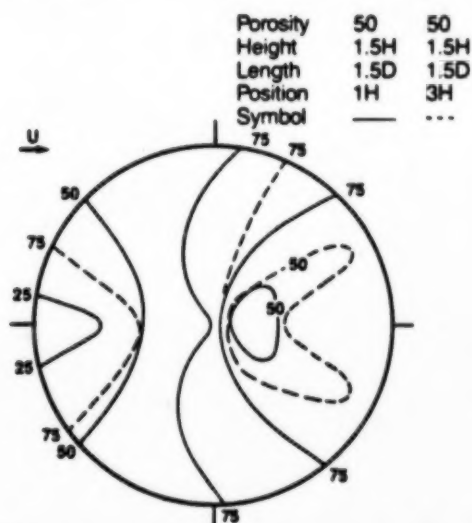


Figure 10. Profile of velocity reduction percent for conical storage pile model with windbreak.

changes and immediately determine the effect of the changes on ESP performance. Work is currently underway to extend and verify the model capabilities to all electrode shapes and to also allow changes in collector geometry.

The program has produced a useful model for fabric filters. The current version of the model does not include electrostatic effects. However, work is underway to introduce the effects of application of electrostatics into the fabric filtration models. A major effort is underway to extend the usefulness of these models to the control of particulate matter from various industrial sources in addition to utilities.

There is additional work being done in fugitive particle control involving the development of engineering design information for hoods used for collection of particles and fume. Operation and maintenance manuals are being developed for ESPs and baghouses. Finally, research is being done to develop technology to decrease the emissions of condensable aerosols.

Conclusion

This paper has presented an overview of the key projects of the EPA particulate technology R&D program, which may be of interest to industry. Work will be continuing in the areas that include ESPs, electrostatically augmented fabric filtration, and control of fugitive emissions. Discussion of specific problems in particulate matter control in industries that may make use of these technology areas would be welcomed.

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Mr. Plaks is Chief, Particulate Technology Branch, Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.